Appendix 6

Habitat Suitability Criteria

This appendix describes the details of determining habitat suitability criteria for selected species. These criteria were used to evaluate the habitat quality within the areas and across the range of flow conditions mapped during this project. Habitat suitability criteria were established based on empirical data (for adult resident fish during summer) as well as literature reviews (spawning life stage). For each species we identified criteria specifying not-suitable, suitable, and suitable-optimal habitat. Habitat models were created for each of the selected indicator fish species (e.g., common shiner, fallfish, American eel, common white sucker, longnose dace, redbreast sunfish, and Atlantic salmon). Additional models were also created for selected benthic macro-invertebrate taxa (e.g., ephemeroptera, plecoptera, trichoptera, odonata) and anadromous fish species (e.g., American shad, alewife, blueback herring).

Empirical data based model.

The empirical set of criteria for rearing and growth (R&G) season had been developed from habitat use data collected in earlier studies. We developed a MS Access database that included all the fish samples collected by our program in the Northeast. It includes observations from 18 rivers presented in the Table A6-1.

Table A6-1: The data sources used for calculation of logistic regression models.

PrjID	Name	# Grids	Description	Species used
1	Upper Souhegan Fish Data	91	Fish data for the Upper Souhegan River including species caught, individual lengths, grid habitat data, and fishing HMU's habitat data	Longnose dace, White sucker, Falfish, Atlantic salmon
2	Upper W.B. Swift Fish Data	100	Fish data for the Upper section of the West Branch of the Swift River, New Salem/Shutesbury, Massachusetts. Including species, grid and HMU habitat attributes and hydraulic measurements data.	
3	Lower Souhegan Fish Data	33	Lower Souhgan River Fish, grid, and fishing HMU data for Site 7 grids; Snorkeling survey for Sites 6, 8, 9, 10, and 11 include fish species with HMU data from nearest-flow mapping.	Common shiner, Longnose dace, White sucker, Falfish
4	Lower W.B. Swift River Fish Data	100	Fish Data for the Lower West Branch Swift River, New Salem, Massachusetts. Electrofishing grids; data includes species, grid and hmu habitat data, and hydraulic measurements.	Atlantic salmon
5	Fort River Fish Data 2006	81	Fish Data collected from the Fort River, Amherst in July of 2006. Fish were collected from the two case study sites of the MesoHABSIM 2006 Summer Course. Data includes species, grid and HMU habitat data, and hydraulic measurements.	Common shiner, Longnose dace, White sucker, Falfish

PrjID	Name	# Grids	Description	Species used
6	Pomperaug River	90	Fish Data collected from the mainstem of the Pomperaug River, CT. Data includes fish species, lengths, grid and HMU habitat data and hydraulic measurements.	Redbreast sunfish Common shiner, Longnose dace, White sucker, Falfish,
7	Nonnewaug River	60	Fish data collected during the Summer of 2004 on the Nonnewaug River (Upper Pomperaug Watershed), CT. Data includes fish species, lengths, HMU and grid habitat data and hydraulic measurements.	Longnose dace, White sucker
8	Weekeepeemee River Fish Data	47	Fish data collected in the Summer of 2004 on the Weekeepeemee River, CT. Data includes species, lengths, grid and HMU habitat data, and hydraulic measurements.	Longnose dace, White sucker
9	Lower Eightmile River Mainstem	97	Fishing survey data collected from the Lower Eightmile River, Mainstem, Connecticut, in July of 2004. Data includes species caught, grid and hmu habitat data, and hydro data.	Redbreast sunfish, Common shiner, White sucker, Falfish, American eel, Atlantic salmon
10	Fenton River 2003	508	Fish data collected on the Fenton River, Connecticut, 2003.	Common shiner, White sucker, Falfish
11	East Branch Eightmile River Fish Data	117	Fishing survey data collected from the mainstem of the East Branch Eightmile River, Connecticut, in July and August of 2004.	Redbreast sunfish, Common shiner, Longnose dace, White sucker, American eel, Atlantic salmon
12	Upper Mainstem Eightmile Fish Survey Data 2004	72	Fishing survey data collected from the Upper Mainstem Eightmile River, Connecticut, in July and August of 2004.	Common shiner, Longnose dace, Falfish, American eel, Atlantic salmon
13	Stony Clove Creek Fishing Survey Data 2002	269	Fishing survey data from the Stony Clove Creek, NY (mainstem) collected in July of 2002.	Longnose dace, White sucker
14	Round Out Fishing Survey Data	106	Fishing survey data from Round Out, NY collected in July of 2002.	
15	Stewart Brook Fishing Survey Data 2002	16	Fishing survey data from Stewart Brook, NY collected in August of 2002.	Common shiner, Longnose dace, White sucker
16	Spring Brook Fishing Survey Data 2002	24	Fishing survey data from Spring Brook, NY collected in August of 2002.	Longnose dace
17	Trout Brook Fishing Survey Data 2002	24	Fishing survey data from Trout Brook, NY collected in August of 2002.	

PrjID	Name	# Grids	Description	Species used
18	Willowemoc Creek Fishing Survey Data 2002	16	Fishing survey data from Willowemoc Creek, NY collected in August of 2002.	
19	Lamprey River BMI Collection Data 2006 & 2007	56	Designated River Instream Flow Study within Site 2 (Grids 1-42) and Site 4 (Grids 43-56).	EPT taxa, Odonates
20	Upper Souhegan River BMI Survey Data 2004	112	BMI Data Collected on the Upper Souhegan River in 2004 as part of the Souhegan River Instream Flow Study.	EPT taxa, Odonates
21	Lower Souhegan River BMI Survey Data 2005	93	BMI collection data from the Lower Souhegan River collected during the Souhegan River Instream Flow Study.	EPT taxa, Odonates

For each fish species (individuals one year of age and older), we analyzed habitat data obtained from rivers where the species has been observed in abundance higher than 5% of a total observations of these species. We used a multivariate statistical model (logistic regression) to compute the habitat selection criteria for adult resident fish species and Atlantic salmon. At each grid and quadrate the physical attributes of the HMU in which it was located were recorded along with the number of individuals and species captured.

To calculate the response functions for the species above, we described each grid that was sampled during the survey in terms of the same environmental characteristics used to develop the habitat database, as well as by the species presence and abundance. The environmental attributes were independent variables and the species were dependent variables in regression models describing habitat preference. We employed a logistic regression model to identify the characteristics of habitat used versus habitat unused by each fish species. The model uses Akaike information criterion (Sakamoto et al 1986) to determine which parameters should be included in the following regression formula:

$$\mathbf{R=e^{-z}}$$

where:

- e = natural log base
- z $= b_1 \cdot x_1 + b_2 \cdot x_2 + \ldots\ldots + b_n \cdot x_n + a$
- $x_{1..n}$ = significant physical attributes
- $b_{1..n}$ = regression coefficients
- a = constant

From the output of the logistic regression function, we obtained two important types of information: the environmental attributes that significantly correspond with species' presence and abundance, and the regression coefficients b-values. The b-values indicate the strength and direction (+ or -) of the association between each habitat attribute and fish presence. Because the selection of right attributes may have critical influence on modeling results, to increase model certainty we applied very rigorous procedure for this purpose.

In the first step, 20% of the randomly selected data is separated to be used for model validation. This data has the same proportion of occupied grids as the whole data set. The regression formula is developed with the remaining 80% of the data.

Subsequently, for each mesohabitat mapped during the biological survey, we calculated the probability of fish presence using computed regression equations and the following formula:

$$\mathbf{p = \frac{e^{z}}{(1+e^{z})}}$$

Where:

- p = probability of presence/high abundance
- e = constant
- $z = b_1 \cdot x_1 + b_2 \cdot x_2 + ... + b_n \cdot x_n + a$
- $x_{1..n}$ = significant physical variables
- $b_{1..n}$ = regression coefficients
- a = constant

In a subsequent step we determined the predictive strength of the model as well as identified thresholds between predictions for suitable and not suitable habitat by comparing probabilities of fish presence with actual observations. We created a Relative Operating Characteristic (ROC) curve for presence predictions (Metz, 1978). The curve examines the discrimination performance of the model over a range of threshold levels by plotting the proportion of grids correctly predicted to be occupied (sensitivity or true positive rate), versus the proportion of grids incorrectly predicted to be occupied (false positive rate). The area under the ROC curve defines the discrimination capacity of the model based on Mann-Whitney statistics (Pearce & Ferrier 2000). The inflection points on the ROC curve allow one to define the probability (Pt) that has the highest true positive rate and lowest false positive rate, and therefore, best separation of occupied and unoccupied areas. In the following assessment, the habitats with a probability of presence greater than Pt were classified as suitable.

To validate model strength we applied the computed formula to the validation data (20%) and compared the number of the fish observations with predictions of suitable habitat. The proportion of correct predictions is recorded as a success rate.

This procedure is repeated for 20 times and each time a new set for randomly selected data is set aside for validation purposes. After 20 runs the model generates a list of parameters that were selected in at least two runs and conducts one more run using only these parameters as input attributes. The success rate of this last model is reported together with the average of success rates from previous runs. If these numbers are relatively close and the average is not much higher then the current success rate, the result is considered satisfactory and the model is considered to be final.

To distinguish suitable habitat, we used binary dependent variables indicating presence and absence. In a second model, we focused on high and low abundances. The fish and data was separated to low and high abundance classes. The cut off value was calculated from observed abundances per grid and was different for each species depending on their behavior (solitary, vs. gregarious) and size. For white suckers, more than three fish indicated high abundance. For fallfish, common shiner, longnose dace, and redbreast sunfish, more than two individuals were needed. For Atlantic Salmon and American Eel, the presence of more than one individual indicated high abundance. There was no abundance model for macro invertebrates. While we used all the available data for the presence and abundance models, we used only data from grids in which fish were caught.

We calculated the probability of presence and of high abundance for every species. The observed presence and abundance at each grid was associated with the probability for the HMU where the grid was located. The suitable habitats with a probability of high abundance greater than selected Pt are deemed optimal. The areas under the curve and Pt values were selected and presented in the results section together with a list of significant parameters and B-values for both the presence and abundance models. The model was then applied to the data from the mapping survey to identify suitable and optimal habitat areas.

For the young-of-the-year (YOY) fish life stage habitat, which consists only of shallow margins, empirical criteria developed on the Quinebaug River were applied. Areas designated as shallow margins had an average depth of 12 cm (SD = 6 cm), and an average velocity of 15 $cm.s^{-1}$ (SD = 11). Substrate in these areas was generally small, ranging from sand to meso-lithal. Shallow margins are an attribute of a HMU and are mapped either as present or abundant. HMUs with abundant shallow margins were considered optimal.

Literature based habitat suitability criteria

Due to the lack of empirical habitat suitability data for the spawning life-stages of the resident indicator fish species and anadromous fish species, a literature review was conducted to determine a set of habitat criteria and parameters defining suitable spawning habitat for each of the selected species. Using this information, a literature-based spawning habitat suitability model was developed based on four habitat attributes (e.g., depth, velocity, choriotop (i.e., substrate type and size), and HMU type) and ranges of acceptable values for each of those attributes. With regard to acceptable ranges of values for each of the four habitat attributes, the spawning habitat requirements of common shiner, fallfish, American eel, common white sucker, longnose dace, redbreast sunfish, Atlantic salmon, American shad, alewife, and blueback herring, were determined. The resulting spawning habitat suitability models were then capable of classifying each of the individual HMUs from all of the mapped flow conditions as “not suitable”, “suitable”, or “suitable-optimal”, based on the measured depth, velocity, and choriotop values and HMU-type classification of each mapped unit.

To determine suitability for a discrete HMU, the HMU's depth, velocity, and choriotop distributions and HMU-type were compared to the ranges specified within the literature. With regard to HMU type, a discrete HMU was considered acceptable if its type is often associated with the other attributes required for spawning by a particular species. For example, a sand-bottom backwater was not considered to be an acceptable HMU for spawning by a species that uses fast-water gravelly areas nor was a gravel-bottom riffle considered suitable for species requiring slack-water sandy conditions for spawning. However, these HMU types *were* considered acceptable for species that do require these respective habitat types for spawning. With regard to hydraulic measurements (7 for depth, 7 for velocity and 7 choriotop descriptions) an HMU was considered to have acceptable ranges for the target fauna if at least three of the seven (or > 0.30) measured/mapped values for each habitat attribute (e.g., depth, velocity, choriotop) within the HMU were within the range of suitable values determined for each species.

For an HMU to be considered "suitable", all three of the hydraulic measurements (depth, velocity and choriotop) must be present within acceptable ranges for at least 30% of the measured values for each attribute. Generally, we presume that all three of the selected attributes (e.g., depth, velocity, choriotop) *and* HMU type need to occur within acceptable ranges for a discrete HMU to be considered "suitable-optimal" spawning habitat (i.e., an HMU must be deemed "suitable" in order to qualify as "suitable-optimal"). However, adjustments were made to the model for individual species whose spawning requirements deviated from the parameters of the model. For instance, in the case of American shad it was determined that spawning habitat suitability for this species was critically dependent upon depth and water velocity conditions for suitable spawning habitat (i.e., if suitable hydraulic conditions were met this species was not dependent upon choriotop characteristics for spawning habitat suitability). Hence, acceptable values of only two attributes, depth and velocity, were required for an HMU to be considered "suitable" for shad spawning. Because of the species strong dependence upon these two factors, HMUs were considered "suitable" having met only these two criteria and "suitable-optimal" if they met only three or more of the four criteria. Backwater mesohabitats were considered "unsuitable" for all species requiring flowing water for spawning. By applying this model to our previously mapped mesohabitats, spawning suitability maps could be created for all of the selected indicator and anadromous fish species.

Results

Table A6-2 represents attributes of both models for common shiner established from 1,014 grids from all rivers including 148 grids where common shiner was captured and 71 grids with high abundance of this species. The presence model consists of a high number of habitat attributes that significantly correspond with observed fish. They describe swiftly flowing but shallow HMUs such as Fastrun accompanied by shallow margins and woody debris. The model also indicates more affinity to coarser substrate and woody deposits. We did not find many Common Shiners in shallow and slow arease areas with shading and undercut banks. The abundance model describes similar swift habitats but with boulders as well as finer gravel and sandy substrate.

Table A6-2: Physical attributes correlating with presence and high abundance of Common Shiner. The Area Under ROC curve is a measure of discrimination capacity of the model (0-1). Selected cut-off indicates the probability separating not suitable, suitable and optimal habitats. B represents regression coefficients of the logistic regression model.

Presence		Abundance	
calibration success	0.828	calibration success	0.7111
estimated success	0.8119	estimated success	0.5019
area under roc	0.7436	area under roc	0.7756
Cutoff	0.22	Cutoff	0.45
Attribute	B	Attribute	B
Constant	-1.7913	Constant	-0.7761
Riprap	0.3922	Boulders	0.6966
Canopy Shading	-0.3636	Canopy Shading	-0.472
Undercut Banks	-0.3043	Depth < 25 cm	-1.1886
Woody Debris	0.3796	Velocity 30-45 cm/s	2.0219
Shallow Margins	0.5133	Velocity 75-90 cm/s	-3.7827
FASTRUN	1.2904	MEGALITHAL	-2.4611
Depth < 25 cm	-1.5265	MICROLITHAL	1.4074
Velocity < 15cm/s	-1.1239	PSAMMAL	5.0552
MEGALITHAL	2.3505	XYLAL	-62.4772
MESOLITHAL	0.8451		
MICROLITHAL	2.1194		
PSAMMAL	-1.6682		
SAPROPEL	-234.3138		
XYLAL	20.3504		

Table A6-3 represents attributes of both models for Longnose Dace established from 900 grids including 300 grids where Longnose Dace were captured and 100 grids with high abundance of this species. The presence model consists of a number of habitat attributes that describe fast flowing shallow HMUs with large gravel and boulders as cover. The abundance model describes riffle and cascade habitats, but with lower velocities, finer substrate and vegetation cover.

Table A6-3: Physical attributes correlating with presence and high abundance of Longnose Dace. The Area Under ROC curve is a measure of the discrimination capacity of the model. Selected cut-off indicates the probability separating not suitable, suitable and optimal habitats. B represents regression coefficients of logistic regression model.

Presence		Abundance	
calibration success	0.7385	calibration success	0.7387
estimated success	0.7176	estimated success	0.6018
area under roc	0.7868	area under roc	0.7548
Cutoff	0.42	Cutoff	0.425
Attribute	B	Attribute	B
Constant	-0.5167	Constant	-1.7396
Boulders	0.2729	Overhanging Vegetation	0.3276
Woody Debris	-0.4197	Submerged Vegetation	0.7564
Clay	1.1732	Clay	2.152
BACKWATER	-1.4963	CASCADE	17.3486
RAPIDS	-1.5701	RIFFLE	0.691
RUN	-1.0942	Depth 25-50 cm	-1.1652
Depth < 25 cm	1.336	Velocity 15-30 cm/s	1.4322
Depth 75-100 cm	-4.5292	DETRITUS	-94.2857
Depth > 125 cm	-456.9524	MICROLITHAL	2.1065
Velocity < 15 cm/s	-1.1611		
Velocity 15-30 cm/s	-0.9166		
MESOLITHAL	0.791		
PSAMMAL	-1.7679		

Table A6-4 represents attributes of both models for Fallfish established from 998 grids including 208 grids where Fallfish were captured and 91 grids with high abundance of this species. The presence model consists of a number of habitat attributes that describe fast flowing ruffle HMUs with moderate depths and shallow margins. The model also indicates more affinity to diversity of substrate. The abundance model describes a positive correlation with deeper riffles and shallow margins.

Table A6-4: Physical attributes correlating with presence and high abundance of Fallfish. The Area Under ROC curve is a measure of the discrimination capacity of the model. Selected cut-off indicates the probability separating not suitable, suitable and optimal habitats. B represents regression coefficients of logistic regression model.

Presence		Abundance	
calibration success	0.7556	calibration success	0.6449
estimated success	0.7647	estimated success	0.5134
area under roc	0.7741	area under roc	0.7022
Cutoff	0.22	Cutoff	0.44
Attribute	B	Attribute	B
Constant	-2.7948	Constant	-1.2201
Boulders	0.3054	Shallow Margins	0.4091
Riprap	0.6588	Clay	1.0456
Overhanging Vegetation	0.3053	RIFFLE	0.7075
Submerged Vegetation	-0.2274	Depth 50-75 cm	-2.1595
Canopy Shading	-0.246	Depth 75-100 cm	6.9026
Shallow Margins	0.193	Velocity 30-45 cm/s	1.3845
Clay	0.5836	MEGALITHAL	2.283
CASCADE	-19.2454	PSAMMAL	1.8206
GLIDE	-0.3483		
RAPIDS	-20.5625		
RUFFLE	0.737		
SIDEARM	-3.1591		
Depth 25-50 cm	1.1163		
Velocity <15 cm/s	0.6521		
Velocity 75-90 cm/s	-15.0809		
Velocity >105 cm/s	-501.0444		
DETRITUS	-11.9683		
MEGALITHAL	1.4696		
MICROLITHAL	1.6271		
PHYTAL	8.8355		
SAPROPEL	-11.7599		
XYLAL	23.9078		

Table A6-5 represents attributes of both models for White Sucker established from 1,481 grids including 241 grids where White Suckers were captured and 57 grids with high abundance of this species. The presence model indicates affinity to finer substrate and slower HMUs with moderate depths. The abundance model describes deeper habitats.

Table A6-5: Physical attributes correlating with presence and high abundance of White Sucker. The Area Under ROC curve is a measure of the discrimination capacity of the model. Selected cut-off indicates the probability separating not suitable, suitable and optimal habitats. B represents regression coefficients of logistic regression model.

Presence		Abundance	
calibration success	0.8107	calibration success	0.7761
estimated success	0.7538	estimated success	0.702
area under roc	0.7056	area under roc	0.7747
Cutoff	0.3	Cutoff	0.3
Attribute	B	Attribute	B
Constant	-1.2099	Constant	-1.527
Submerged Vegetation	-0.2113	FASTRUN	20.1957
Canopy Shading	-0.3195	RIFFLE	-1.4374
Shallow Margins	-0.1436	SIDEARM	-18.1324
BACKWATER	1.0705	Depth 75-100 cm	5.9629
Depth 25-50 cm	0.685	Depth 100-125 cm	-310.8309
Velocity 30-45 cm/s	-1.2796	Velocity <15 cm/s	1.2638
Velocity 60-75 cm/s	-3.7866	DETRITUS	-14.6898
MEGALITHAL	-1.0125	MEGALITHAL	-4.2506
MICROLITHAL	1.5534	XYLAL	-528.5686
PELAL	-3.8743		
PHYTAL	-11.1237		
PSAMMAL	0.972		
SAPROPEL	-4.1275		

Table A6-6 represents attributes of the presence model for Redbreast Sunfish established from 304 grids including 77 grids where Common Shiners were captured and 19 grids with a high abundance of this species. The presence model indicates affinity with deeper HMUs with vegetation and woody debris.

Table A6-6: Physical attributes correlating with presence and high abundance of Redbreast Sunfish. The Area Under ROC curve is a measure of the discrimination capacity of the model. Selected cut-off indicates the probability separating not suitable, suitable and optimal habitats. B represents regression coefficients of logistic regression model.

Presence		Abundance	
calibration.success	0.7874	calibration.success	0.6438
estimated.success	0.6847	estimated.success	0.5077
area.under.roc	0.8028	area.under.roc	0.6641
Cutoff	0.39	Cutoff	0.31
Attribute	B	Attribute	B
Constant	-2.7757	Constant	-0.6258
Submerged.Vegitation	0.8923	RIFFLE	-16.1495
Woody.Debris	0.5964	MACROLITHAL	-3.7514
POOL	1.2987		
RIFFLE	-1.3216		
RUFFLE	0.8205		
SIDEARM	-16.425		
Velocity 60-75 cm/s	-9.1681		
DETRITUS	-14.0895		
MEGALITHAL	2.8547		
MESOLITHAL	1.7921		
PSAMMAL	-1.3248		
XYLAL	72.989		

Table A7-6 represents attributes of both models for Atlantic Salmon established from 477 grids including 81 grids where Atlantic Salmon were captured and 24 grids with high abundance of this species. The presence model consists of a number of habitat HMUs attributes that describe fast flowing run, cascade, and plungepool habitat with gravel. The abundance model shows correlation with riffles and woody debris.

Table A7-6: Physical attributes correlating with presence and high abundance of Atlantic Salmon. The Area Under ROC curve is a measure of the discrimination capacity of the model. Selected cut-off indicates the probability separating not suitable, suitable and optimal habitats. B represents regression coefficients of logistic regression model.

Presence		Abundance	
calibration success	0.8746	calibration success	0.8148
estimated success	0.8396	estimated success	0.6
area under roc	0.8514	area under roc	0.8395
Cutoff	0.3	Cutoff	0.54
Attribute	B	Attribute	B
Constant	0.6766	Constant	-2.7475
Boulders	-0.7899	Overhanging Vegetation	1.3919
Submerged Vegetation	-0.7037	GLIDE	1.9562
CASCADE	1.3733	POOL	-16.2258
PLUNGEPOOL	2.5379	RUFFLE	1.7966
RUN	0.6263	Velocity 30-45 cm/s	3.1916
Depth 50-75 cm	-2.4275	MEGALITHAL	-8.4493
Velocity < 15 cm/s	-3.7932		
Velocity 15-30 cm/s	-1.9773		
Velocity 45-60cm/s	-4.1753		
DETRITUS	-466.0512		
MICROLITHAL	3.105		
PHYTAL	-13.2868		

Table A6-8 represents attributes of both models for American Eel established from 377 grids including 108 grids where American Eels were captured and 36 grids with a high abundance of this species. The presence model indicates affinity vegetation, shading and undercut banks. The abundance model shows a correlation with pool and riffle habitats and boulder cover and submerged vegetation.

Table A6-8: Physical attributes correlating with presence and high abundance of American eel. The Area Under ROC curve is a measure of the discrimination capacity of the model. Selected cut-off indicates the probability separating not suitable, suitable and optimal habitats. B represents regression coefficients of logistic regression model.

Presence		Abundance	
calibration success	0.7311	calibration success	0.7339
estimated success	0.6888	estimated success	0.5214
area under roc	0.8078	area under roc	0.8127
Cutoff	0.31	Cutoff	0.42
Attribute	B	Attribute	B
Constant	-0.6756	Constant	-1.739
Overhanging Vegetation	0.4093	Boulders	0.8116
Submerged Vegetation	0.2857	Submerged Vegetation	1.1312
Canopy Shading	0.7697	Woody Debris	-0.5763
Undercut Banks	0.3364	POOL	11.893
GLIDE	-1.5625	RIFFLE	1.1648
RUN	-0.9556	SIDEARM	-18.6019
Depth > 125cm	-469.6871	Depth 75-100cm	-80.2693
Velocity -15	-1.2515	Velocity >105 cm/s	311.6292
Velocity 45-60cm/s	-4.3325	DETRITUS	-287.6061
AKAL	-2.4915	XYLAL	216.3294
MEGALITHAL	-2.2301		
PELAL	-6.4175		
PHYTAL	-38.4187		
PSAMMAL	-1.7826		
SAPROPEL	3.1383		

For macro-invertebrates we developed only presence models, as data on high and low abundance was not available. Table A6-9 represents attributes for family Ephemeroptera established from 266 quadrates including 146 quadrates where these animals were found. The model indicates affinity to fast flowing shallow habitats or habitat with fine gravel.

Table A6-9: Physical attributes correlating with presence and high abundance of Ephemeropterans. The Area Under ROC curve is a measure of the discrimination capacity of the model. Selected cut-off indicates the probability separating not suitable, suitable and optimal habitats. B represents regression coefficients of logistic regression model.

Presence	
calibration success	0.7471
estimated success	0.6794
area under roc	0.8547
Cutoff	0.6021
Attribute	**B**
Constant	-0.3204
Clay	28.164
GLIDE	1.566
RAPIDS	2.4949
RIFFLE	4.7487
SIDEARM	1.7703
Depth 75-100 cm	-4.6698
Depth > 125 cm	2.7665
Velocity 15-30 cm/s	1.6142
Velocity >105 cm/s	-134.171
MACROLITHAL	-3.2105

Table A6-10 represents attributes for family Plecoptera established from 266 quadrates sampled including 88 quadrates where these animals were found. The presence model indicates affinity to fast flowing shallow habitats.

Table A6-10: Physical attributes correlating with presence and high abundance of plecopterans. The Area Under ROC curve is a measure of the discrimination capacity of the model. Selected cut-off indicates the probability separating not suitable, suitable and optimal habitats. B represents regression coefficients of logistic regression model.

Presence	
calibration success	0.7663
estimated success	0.6843
area under roc	0.8386
Cutoff	0.3612
Attribute	**B**
Constant	0.1743
Overhanging.Vegitation	-0.6206
Canopy.Shading	0.7626
RAPIDS	1.0262
RIFFLE	2.5884
Depth 75-100 cm	-4.3899
Celocity < 15 cm/s	-2.956
velocity 30-45 cm/s	-7.5367
MESOLITHAL	1.7867
MICROLITHAL	-1.9958

Table A6-11 represents attributes for family Tricoptera established from 266 quadrates sampled including 181 quadrates where these animals were found. The model indicates affinity to shallow habitats with large gravel.

Table A6-11: Physical attributes correlating with presence and high abundance of tricopterans. The Area Under ROC curve is a measure of the discrimination capacity of the model. Selected cut-off indicates the probability separating not suitable, suitable and optimal habitats. B represents regression coefficients of logistic regression model.

Presence	
calibration success	0.6973
estimated success	0.6216
area under roc	0.7589
Cutoff	0.6741
Attribute	B
Constant	0.2226
BACKWATER	-1.6865
SIDEARM	-1.3965
Depth <25 cm	3.6023
MESOLITHAL	1.5417
MICROLITHAL	-1.4871

Table A6-12 represents attributes for family Odonata established from 266 quadrates sampled including 71 quadrates where these animals were found. The model indicates affinity to glide habitats with undercut banks.

Table A6-12: Physical attributes correlating with presence and high abundance of odonates. The Area Under ROC curve is a measure of the discrimination capacity of the model. Selected cut-off indicates the probability separating not suitable, suitable and optimal habitats. B represents regression coefficients of logistic regression model.

Presence	
calibration success	0.5862
estimated success	0.6431
area under roc	0.7069
Cutoff	0.3039
Attribute	B
Constant	-0.8288
Undercut.Banks	1.1165
GLIDE	1.7451
Velocity 45-60 cm/s	-3.6847
Velocity 60-75 cm/s	-3.2659

Spawning habitat

Our literature survey of the spawning requirements of selected resident indicator and anadromous fish species allowed us to identify the habitat attributes and conditions (ranges of values) necessary to determine “not suitable”, “suitable”, and “suitable-optimal” spawning habitat for these species. The seasonal timing, specific water temperature range, and strategies of spawning were also specified for each species but were not used as inputs in our spawning habitat suitability model. Table A6-13 presents the spawning habitat characteristics established for each of the selected species based on our literature survey.

Table A6-13. Spawning habitat suitability criteria* for the resident indicator and anadromous fish species of the Lamprey Designated River, New Hampshire.

Resident Indicator Fish Species	Seasonal Period	Water Temp.	Optimal Meso-Habitat	Water Depth	Current Velocity	Choriotop (Substrate)	Comments
Common Shiner	May through Mid-July	15.5-21.0°C	Riffles (Ruffles)	<20 cm	15-40 cm/s	Psammal, Akal, Micro	Spawns over nests of other minnows
Fallfish	Late April through Early June	15.0-19.0°C	Glides, Pools, Runs	<=99 cm	<20 cm/s	Akal, Micro	Gravel nests built by male; nest building may initiate spawning behavior in females
Longnose Dace	May through Early July	15.5-21.0°C	Riffles (Ruffles), Rapids	<20 cm	45-59 cm/s	Micro, Meso, Macro	No nest; male guards eggs/territory
Redbreast Sunfish	May-August	20.0-25.0°C	Runs, Pools, Glides	25-150 cm	<30cm/s	Psammal; Akal	Cover is critical (boulders, woody debris); MG-Riverine
White Sucker	Mid-April Through May	10.0-20.0°C	Riffles (Ruffles)	<50 cm	15-55 cm/s	Akal, Micro, Meso	Upstream spawning migrations

Anadromous Fish Species	Seasonal Period	Water Temp.	Meso-Habitat	Water Depth	Current Velocity	Choriotop (Substrate)	Comments
Alewife	May – July (as late as August possible)	10.5-16.0°C 15.0-20.0°C		15-300 cm	Slow 0-14cm/s	Akal, Detrital, Micro, Pelal, Psammal	Submerged vegetation
American Shad	May through Mid-June	Range: 8-26°C Peak: 14-21.0°C	Run, Glide, Pool, Fast Run	51-125 cm+	16-104 cm/s	Psammal, Akal, Micro, Meso	Depth/ velocity dependent
Atlantic Salmon	October through Early December	4.4-10.0°C	Riffle, Run, Glide, Ruffle, Rapid, Sidearm	25-74 cm	30-74 cm/s	Micro	Substrate-dependent (Gravel); Mean Froude # ~ 0.3 (Moir et al. 1998)
Blueback Herring	May – July (as late as August possible)	14.0-26.0°C 20.0-24.0°C		51-125 cm+	Swift 16-104cm/s	Akal, Micro, Meso	

Discussion

The models presented here all have a satisfying capacity to discriminate between occupied and not occupied habitats, which is indicated by high areas under ROC curves. The models also correspond well with empirical expectations. For example, all fluvial specialists show clear affinity towards fast flowing, riffle habitats. The habitat for fluvial dependent species such as White Sucker and Common Shiner is characterized by swift but deeper areas. In some of the models individual attributes received very high coefficient value (eg. XYLAL for white sucker with -529). This is most likely due to the fact that only few samples with these attributes were available and the result is more due to coincident than showing real pattern. We conducted model sensitivity analysis of the model by excluding these attributes and resulting models proved to be insignificantly different. Consequently we used the original models without any exclusion. The only exception was the model for Redbreast Sunfish which indicated high affinity of this species with rapids, based on 2 out of 304 observations that happened to be in rapid HMU. This result was unreasonable and the model has been recalculated without including presence of rapids as an independent variable.

Because fish models are developed for individual species and on a very large database, they may be more reliable than those for invertebrates. On the other hand, lower mobility of invertebrate fauna reduces the impact of coincidence on the observations. The family of odonates occupies wide range of habitats and therefore the model presented here need to be view with caution. However, we found only a few species in our samples with similar habitat use.

The literature based spawning model presented here has the capacity to discriminate between and identify “not suitable”, “suitable”, and “suitable-optimal” habitat units. It is a more conservative and robust version of similar literature-based models previously used to identify the level of suitability of habitats for spawning on the Quinebaug River and Souhegan River. The current model requires that at least three out of the seven measured values for an attribute be met in order for the attribute to be considered as having met the criteria. It also requires that all three habitat attributes (depth, velocity, and choriotop) exist in acceptable proportions within an HMU for that unit to be considered as suitable. Previous models required either lower proportions of measured values for the consideration of individual attributes as suitable or did not require that all three of the habitat attributes be present in acceptable proportions together within a unit for the unit to be considered suitable. The changes made to this model seem to have strengthened it by requiring a greater portion of measured values to meet the criteria developed for each species in order to be considered suitable or optimal. This assures us that a more substantial area of the habitat possesses the defined attributes than in the previous models. Although these changes may cause decreases in the amount of “suitable” and “suitable-optimal” spawning habitat throughout the river due to its more conservative standards, our confidence in the accuracy of its ability to identify actual suitable conditions within the mapped habitat units is increased. Overall this model provides the ability to identify suitable spawning habitat for the selected species at various flows when applied to habitat mappings of the river conducted under multiple flow conditions.

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